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ACTA POLYTECHNICA SCANDINAVICA

CIVIL ENGINEERING AND BUILDING CONSTRUCTION SERIES No. 4

IVAR J. JOHANNESSEN

Test Section and Installation of Test Equipment I

Oslo Subway

KJELL ØYEN

An Earth Pressure Cell for Use on Sheet Piles II

Oslo Subway

Norwegian Contribution No. 5

Trondheim 1960

Also published in the Proceedings of the Brussels Conference 1958
on Earth Pressure Problems

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SUMMARY

In connection with the construction of Oslo Subway, earth pressure measurements were made in a strutted excavation in soft silty clay.

This article presents a description of the test section, with a summary of soil properties. All the measurements were made in a cross section of the excavation, the excavation being approximately 28 meters long.

On both sides of the excavation earth pressure cells and vibrating wire strain gauges for measuring earth pressure and stresses in the sheet piling, were installed directly on the sheet piles. The struts were equipped with vibrating wire strain gauges for measuring strut loads.

In addition, specially settlement stakes and piezometer points were installed to measure the settlements and changes in pore water pressure during construction.

This article describes further the installation of testing equipment, together with a record of the practical experiences obtained.

1. INTRODUCTION

In an attempt to obtain further information on the earth pressures and stress distributions along strutted sheet piles in clay, and on the stresses set up in the struts, field measurements were carried out in connection with the construction of a new section of the Oslo Subway.

The Subway will partly pass through soft, silty marine clay and it was clear that the construction would present many difficulties. The first section was, therefore made as an experimental excavation to investigate the method of construction.

This article describes the test section, the relevant soil properties, and the installation of the testing equipment, together with a record of the practical experiences obtained.

2. SOIL CONDITIONS

In connection with the preliminary design of the Subway, field investigations were carried out some years ago. The investigations near to the test section included four vane tests and one undisturbed sample boring. The location of these borings is shown

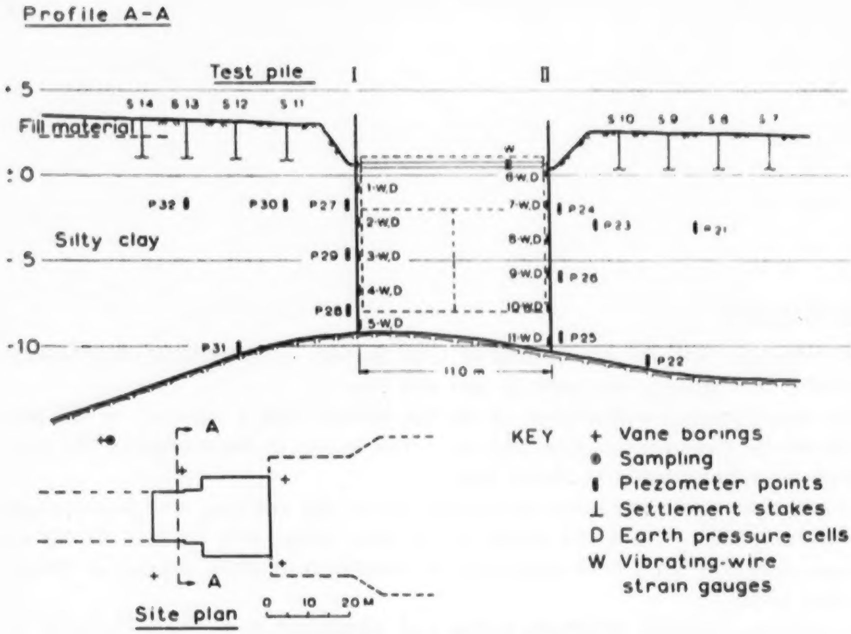

Fig. 1. Profile and site plan of test section.

in Fig. 1. During excavation, undisturbed chunk samples 20 cm in diameter, and 30 cm long were also taken.

A summary of the results obtained from these borings and chunk samples is given in Fig. 2.

The upper layer, approximately of 1 m thickness, consists of fill material of mainly stone and gravel. From this depth to rock found at about 13 meters below surface, a silty clay was encountered, the uppper part of which is slightly weathered. Below this weathered zone, the clay shows a linear increase in undrained shear strength with depth down to 6,5 meters below ground surface, where a decrease in shear strength is found, after which the shear strength increases again with depth, as is usual for normally consolidated clays. The average value of the undrained shear strength is approximately 2,5 t/m^2.

3. GENERAL DESCRIPTION OF THE TEST SECTION

A site plan of the experimental excavation is shown in Fig. 1. The eastern part of the excavation is about 18 meters wide and 16 meters long, and forms part of the future station. The western part forming the tunnel section is approximately 11 meters wide and 12 meters long, and was chosen for the test section.

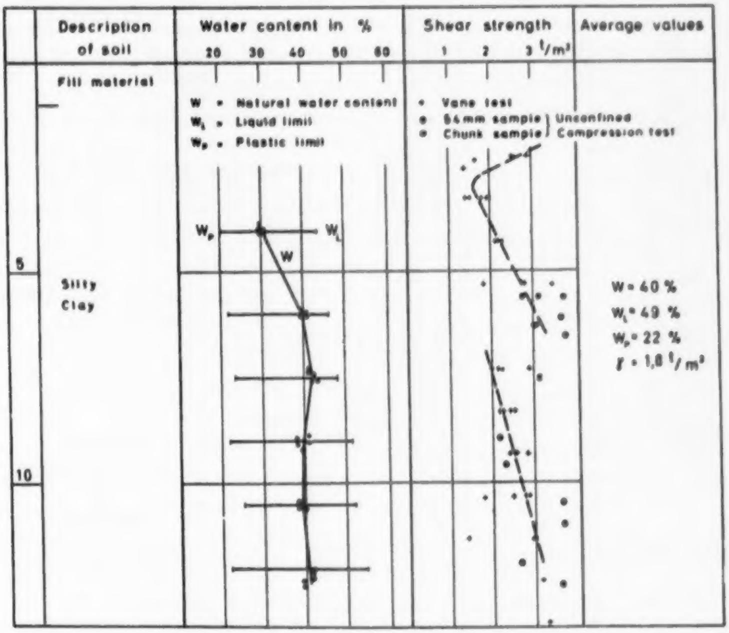

Fig. 2. Soil properties.

Steel sheet piling, Type Belval Z IV N 50 was used over the whole job, and driven down to rock. After contact with the rock, each steel pile, excluding the test piles, was secured to the rock by further driving with several blows of a special 1.000 kg sheet piling hammer.

The locations of all installations in the test section is shown in Fig. 1.

To measure the settlements of the soil mass, special steel stakes, 8 in all, were placed in a cross section, four on each side of the excavation.

Twelve piezometers were used to measure the pore pressure at different points near the excavation. Six of these, three on each side, were placed at different depths only 0,5 meters from the sheet piling.

Eleven earth pressure cells, five on one and six on the other side of the excavation, were installed directly on the sheet piles. The lower cells were placed 0,50 meters above the lower end of the sheet piles, the other cells being placed on a vertical line at intervals of 2 meters.

To measure the distribution of longitudinal stresses in the sheet piles, vibrating wire strain gauges were installed in couple, one on each side of the sheet pile, Fig. 3 c, at the same level as the earth pressure cells.

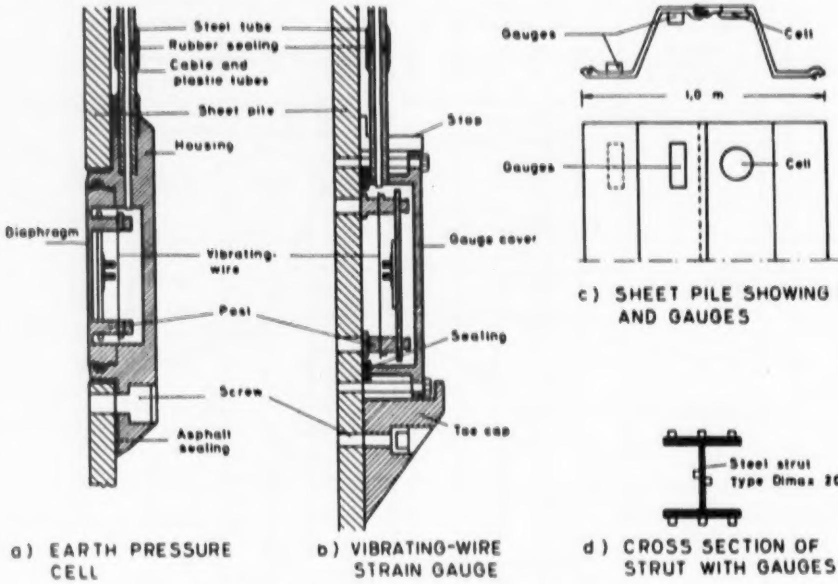

Fig. 3. Location of test equipment on piles and struts.

To measure strut loads, vibrating wire strain gauges were placed on two struts in a depth of 2,3 meters below ground level. On each strut eight gauges were attached as shown in Fig. 3 d.

The intention was to measure the deformation of the sheet piles using an inclinometer, based on resistance strain gauges (Plantema 1953). A channel-like profile, in which the inclinometer should run, was fastened to the inside of each test pile.

The horizontal distance between the sheet piles was measured as the excavation proceeded.

4. INSTALLATION OF TEST EQUIPMENT

The earth pressure cells, used for these tests are fully described by K. Øien (1958).

The cells were placed in holes, cut out at the sheet pile by a torch, and fitted by 5 screws. The cells were fastened and tightened in such a way that the diaphragms were flush with the faces on which the earth pressure was to be measured, Fig. 3 a. Asphalt was smeared around the holdes to avoid any leakage at the junction between cells and sheet piles.

The vibrating-wire strain gauges are of the type developed at the Building Research Station. A slight modification, however, was made in the design of fastening the wire, to insure that it would not loosen when driving the pile. The wire was secured with a selflocking set screw, and in addition this screw was locked with a locknut on the top.

The gaugecover made of cast iron was fitted to the pile whith two screws (Fig. 3 b). Between the pile and the gauge-cover a flexible sealing compound (Expendite R.B. 200) was applied to make the installation watertight. Before applying this sealing, the pile surface was heated, to obtain better adhesion. In addition, each gauge was covered with apshalt. Below each gauge a steelwedge toe cap was fitted as a protection during pile driving.

Most of the strain gauges on test pile I, showed after driving to be out of action; the reason for this was thought to be leakage through the sealing. The strain gauges on test pile II were therefore, in addition to the described procedure, covered with a thin iron casing, which was filled with grease.

The connecting cables from the cells and strain gauges were carried up to ground level inside steel tubes. Not only were the points between the steel tubes and gauges tightened as a precaution against leakage, but rubber seals were also placed around the cables at the junction of both the gauges and the cells.

Through two plastic tubes running inside the same steel tube as the connecting cables, it was possible to blow dry air through the waterproofed pressure cells and gauges to prevent condensation of water. The same plastic tubes insured that the air pressure inside the earth pressure cells would always be atmospheric.

The zero readings (i.e. no bending stresses in the pile) of the vibrating wire strain gauges were taken when the test piles were hanging vertically at the site. At the same position the zero readings (i.e. no pressure at the diaphragm) were taken for the earth pressure cells. The zero reading at the struts were taken when the struts were laying horizontally, supported at both ends.

Before the sheet piles were driven, the upper 2,7 meters of soil was excavated as shown in Fig. 1. Some of the piles required extremely hard driving and it was feared that the testing equipment would not withstand such treatment. In an attempt to produce easier driving conditions, and to reduce the danger of damage of the testing equipment, the test piles were thoroughly soaped to reduce skin friction, while a wash boring nozzle was installed at the pile end to reduce the point resistance. The wash boring nozzle was installed only on the inside of the sheet piles, to awoid disturbing of the tests. In spite of these arrangements, the driving was fairly hard, especially for test pile II. With a hammer weight of 1 ton, 100 blows were necessary to produce a pile penetration of 1 meter with a drop height of 0,40 meters.

5. CLOSING REMARKS

Every earth pressure cell functioned satisfactorily after driving. Most of the vibrating wire strain gauges, unfortunately, were found to be out of action after driving. After excavation, it was found that the cover of each faulty gauge was filled with water. This was due in some cases to the sealing not being tight enough, and in others to the covers being tightened too severely and pinching the sealing in two.

Because of the large variations in temperature which influenced the readings when measurements were taken, the inclinometer was not useable for exact measurements of the deformation. The difference in readings, due to the sensitivity of the inclinometer with respect to temperature corresponds to deformations of the same order as assumed to be measured at the sheet piling.

6. ACKNOWLEDGEMENT

The author wishes to thank the Authority of Oslo for permission to publish this paper.

The author wishes further to express his gratitude to Mr. B. Kjærnsli, who was responsible for the planning of the test section and for his assistance during the preparation of this paper, and finally to Mr. A. Angvik for his aid in carrying out the installations.

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SUMMARY

This paper describes an extremely robust earth pressure cell, for use on sheet-piles driven into a deposit of soft clay. The operation of the cell depends on the variation in the natural frequency of a steel wire stretched between two arms in a diaphragm, caused by a change of the stress in the wire. When an external pressure acts on the diaphragm, the stress in the wire increases and accordingly its natural frequency. The frequency is measured by an instrument constructed at the Building Research Station, Watford, England.

The cell is calibrated against water pressure, and the calibration curve is approximately linear, but shows that the cell possesses some degree of hysteresis.

The cell is constructed for a maximum pressure of 2.5 kg/cm^2, and its over-all accuracy is ± 3 per cent of the full load pressure.

1. INTRODUCTION

In the design of earth structures and foundations, engineers are forced to make certain assumptions and simplifications which may not be fulfilled in nature. Measurements in the field are therefore a very helpful tool for these engineers.

In connection with the development of the Oslo Subway, the Norwegian Geotechnical Institute was asked to deliver various types of measuring equipment, including an earth pressure cell, which could be mounted on a sheet pile, and driven together with it into a deposit of soft clay. The purpose of the measurements is to obtain a more reliable basis for the design in the future construction of Oslo Subway.

For more than a year, the Norwegian Geotechnical Institute has endeavoured to produce an earth pressure cell robust enough to withstand the driving of the sheet pile, without changing its zero reading. In the final design of the pressure cell the Institute has succeeded in developing such a cell.

2. THE WORKING PRINCIPLE OF THE PRESSURE CELL

The basic principle of the pressure cell depends on the variation in the natural frequency of a stretched steel wire caused by a change in the stress in the wire.

The steel wire is stretched between two arms on a diaphragm, and is set in vibrations by an electromagnet. The magnet is also used as the pick-up for the vibrations.

The relationship between the natural frequency and the stress in the wire is given by the equation:

$$f = \frac{1}{2L}\sqrt{\frac{\sigma}{\varrho}}$$

where f — natural frequency of the wire in sec^{-1}

L — free length of the wire in cm

σ — stress in the wire in $dynes/cm^2$

ϱ — density of wire material in g/cm^3

When an external pressure is applied to the diaphragm, the two arms will, due to the deflection of the diaphragm, tilt slightly, and cause an increase in stress in the wire.

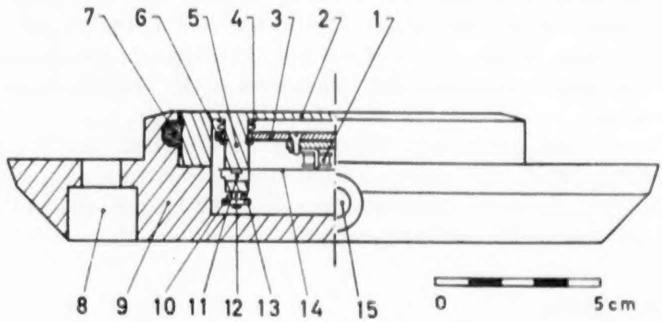

Fig. 1. Cross section through the pressure cell

1. *Electromagnet*
2. *Diaphragm*
3. *Insulation strip for electromagnet*
4. *Sota spring washers*
5. *Arm*
6. *Seeger ring*
7. *Angus ring*
8. *Hole for fitting screw*

8. *Housing*
10. *Locking nut*
11. *Pin for fastening the wire*
12. *Umbraco screw*
13. *Spring washer*
14. *Steel wire*
15. *Connecting cable entrance*

3. THE CONSTRUCTION OF THE PRESSURE CELL

The cell consists of a diaphragm, and a housing. The diaphragm is a 2.5 mm thick plate with two arms set a distance 57 mm apart and an outer ring of 10 mm thickness and a height of 14 mm. The entire diaphragm is made out of one piece of material. The diaphragm rests on a shoulder in the housing and is held in position by an angus ring, to minimize the transfer of stresses from the housing to the diaphragm. Both the diaphragm and the housing are made from mild carbon steel. Fig. 1 shows a cross

Fig. 2. Photograph of the pressure cell and the diaphragm.

section through the cell and Fig. 2 gives a photograph of the cell. Beside the cell is seen the inner face of a diaphragm.

The diaphragm is dimensioned for a pressure up to 2.5 kg/cm². At this pressure the maximum stress in the diaphragm is about 420 kg/cm², and the central deflection is found to be 0.037 mm. According to an investigation carried out by U.S. Waterways Experiment Station (1944), the diameter/deflection ratio should exceed 1000, for a pressure cell mounted flush with the surface of a rigid wall facing up to a loose sand mass. In the pressure cell described in this paper this ratio is about 2000 for a pressure of 2.5 kg/cm².

The housing, seen in Fig. 1, is also made out of one piece of material. The ring at the top of the housing with a groove for an angus ring surrounds the diaphragm, and has a height equal to the thickness of the sheet-pile on which it is to be mounted, so that the diaphragm lies flush with the surface of the sheet-pile. Two sides of the housing are cut (as seen from Fig. 2) to accomodate the sheet-pile profile which was to be used, viz. Belval Z IV N 50.

The diaphragm and the housing forms a closed chamber into which the connecting cable enters through a hole in the housing. The cable entrance is made waterproof by a squeezed rubber packing. Two plastic tubes are led together with the connecting cable into the cell chamber, to maintain atmospheric pressure in the chamber and also to force dried air through the system to prevent condensation in the chamber. The connecting cable and the plastic tubes are protected by a ¼″ steel tube.

The thickness of the cell is 38 mm, and of this only 24 mm protrudes into the soil, and offers very little resistance to driving. The cell is secured to the pile by five screws. For further information concerning the installation of the pressure cell on the sheet pile, see the article by I. J. Johannessen (1958). The results of the measurements are given by B. Kjærnsli (1958).

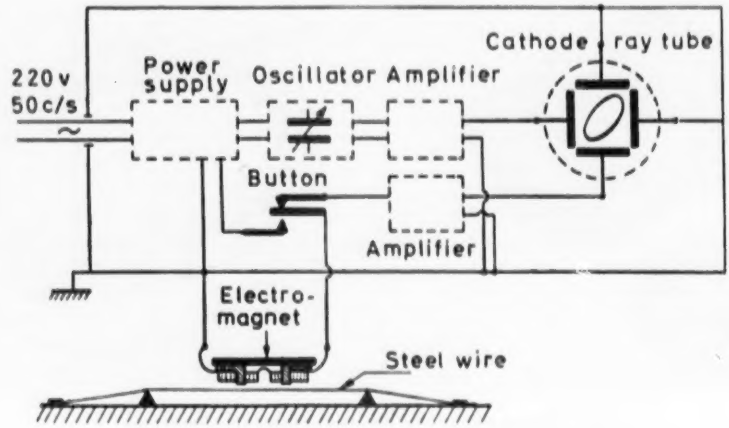

Fig. 3. Block diagram of the recording instrument.

4. FREQUENCY MEASUREMENT

The frequency measurement is taken by an instrument built by the Central Institute for Industrial Research, Norway, following a drawing kindly loaned to the Norwegian Geotechnical Institute by the Building Research Station, Watford, England. The instrument consists of a power supply, an electric oscillator with adjustable frequency, a cathod ray tube and two amplifiers, one for the oscillator signal and one for the gauge signal. A block diagram of the instrument is given in Fig. 3.

The measurement is made as follows:

By pressing a buttom on the instrument, an electric impulse is sent through the coils of the electromagnet. This impulse will increase the magnetic attractive force, and when the impulse ceases, the steel wire vibrates in a magnetic field. This vibration causes changes in the magnetic field, and an alternating electromotive force (e.m.f.) is induced in the coils. This induced e.m.f. is led through an amplifier to one of the sets of plates in the cathode ray tube. The frequency of the induced e.m.f. is equal to the frequency of the wire.

The signal from the oscillator is led to the other set of plates in the cathode ray tube. By adjusting the frequency of the oscillator signal, this can be made equal to the frequency of the vibrating wire. When an ellipse is seen on the screen of the cathode ray tube, these two frequencies are synchronized. A reading is taken on a scale and when this scale is calibrated, the frequency of the wire is known.

5. CALIBRATION OF THE PRESSURE CELL

The cell was mounted on a wall of a waterfilled pressure chamber in the same way as it would be on the sheet pile. The water pressure was measured by a mercury manometer. A typical calibration curve is given in Fig. 4, where the value of $(f^2 - f_0^2) . 10^{-3}$

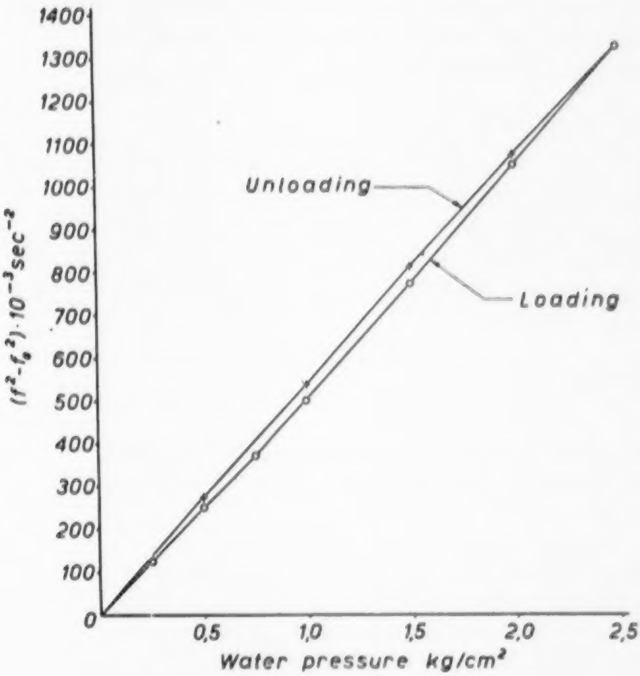

Fig. 4. Typical calibration curve.

is plotted against the pressure, f_0 being the frequency of the wire at zero pressure. As it is seen, the cell possesses some degree of hysteresis, which was impossible to get rid of by repeated loading and unloading the cell. An attempt was made to calibrate the cell by pressing it against soft clay, but this calibration curve was only slightly different from the calibration curve obtained by calibrating against water pressure. Due to the simplicity and time saved, this latter method was adopted.

The cell is very sensitive, one can read a change in the frequency of the wire at a pressure of $2{,}5.10^{-3}$ kg/cm applied on the diaphragm, but the accuracy of a measurement taken in the field is far from this value. There are several factors that affect the accuracy, such as: Hysteresis, zero drift, temperature variations and the accuracy with which one can measure the frequency of the wire. The zero drift is $\pm$ 5 c/s and the accuracy of the frequency measurement is $\pm$ 2c/s. An increase in temperature troughout the cell of 10° C decreases the frequency of the wire by 5 c/s. If the surface of the diaphragm is held at one temperature and the housing at another higher temperature, a temperature difference of 10° C gives a decrease in the frequency of 28 c/s. The earth pressure cell measures the total pressure acting normal to the diaphragm, i.e. the pressure from both the solid and the liquid phases of the medium. The influence

on the reading of a force acting parallel to the surface of the diaphragm is negligible. Taking into account these factors, the over-all accuracy is about $\pm$ 3 per cent of full load pressure, i.e. $\pm 0{,}075$ kg/cm^2.

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